PERFORMANCE AND RELIABILITY OF BEAM DELIVERY UNIT FOR ADVANCED LITHOGRAPHY

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ABSTRACT

With the advent of advanced 193 nm systems processing 300 mm wafers, the production lithography cell is about to undergo a technology shift. This is because processing 300 mm wafers requires introduction of several new technologies. These include technologies that enable increasing light source power at 193 nm—the NA of the projection lens and the speed of scanner stages. Coupled with the need to maintaining high wafer throughput, the scanners must also deliver very tight CD control to within few nm, (typically less than 3 nm). Cymer, Inc. believes that certain key technologies—traditionally ignored at 248 nm for 200 mm wafers—must be revisited. This paper pertains to one such technology: the mechanism to deliver stable light from the light source to the input of the scanner. We refer to this as the Beam Delivery Unit (BDU). To support these changes, Cymer has developed a BDU that will guarantee a stable beam at the scanner entrance, during exposure.

There are three aspects to beam stability: 1. Optical transmission, 2. Beam positioning and, 3. Beam angle. Position stability impacts dose stability (energy per pulse integrated over several pulses) at the wafer and pointing instability adversely affects the illumination uniformity at the reticle. To the lithography process engineers, the effects of beam stability are not new; both result in loss of CD control. At □130 nm node, the loss of CD control due to beam instability was insignificant, therefore ignored. However, below that node, we will show that unless the beam exiting the BDU is stabilized in position and pointing, the loss in CD control is of the order or 1 nm, which is a significant portion of the total CD control budget. For example, for MPU gate node of 65 nm, the ITRS roadmap allocates CD control of 3.7 nm. Thus, the 1 nm loss of CD control due to aforementioned instability alone is considered to be very significant. To address this critical loss in CD control, Cymer has implemented a novel beam stabilization control system in the BDU. Such beam stabilization maintains beam position and pointing during exposure of a die of a wafer, virtually eliminating CD control errors. Cymer has also incorporated reliable BDU materials technology that maintains stable transmission over several years of operation. Cymer's beam stabilization control system is the subject of this paper.

Keywords: Beam Stabilization, Lithography, Beam Delivery Unit, Reticle Illumination

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1.0 Introduction

With the advent of advanced 193 nm systems processing 300 mm wafers, the production lithography cell has undergone a technology shift. This is because processing 300 mm wafers required introduction of several new technologies. These included technologies that enable increasing laser power at 193 nm, the NA of the projection lens and the speed of scanner stages. Coupled with the need to maintaining high wafer throughput, the scanners must also deliver very tight CD control to within few nm (typically less than 3 nm). The author believes that certain key technologies- traditionally ignored at 248 nm for 200 mm wafers must be revisited. This paper pertains to one such technology - the mechanism to deliver stable light from the laser to the input of the scanner [31]. We refer to this as the Beam Delivery Unit (BDU). With a BDU, all laser performance specifications, traditionally defined at the laser exit, are now defined at the BDU exit. The BDU exit is the input to the scanner – the point of use of the laser beam. Thus, the BDU is simply an extension to the laser and this unit should be integrated with the laser.

2.0 Description

A typical BDU connecting a laser to a scanner is shown in Figure 1 and the details are shown in Figure 2. The total length of the BDU can be between 5 m and 20 m. Although we show a 2 mirror BDU, in practice a BDU can comprise of 3 to 5 mirrors. In all scanners, an attenuator is used to regulate dose at the wafer. The technology ofr the attenuator presented here suggests that the correct location of the attenuator is at the laser exit rather than somewhere inside the scanner. The attenuator is still under the control of the scanner and is used to vary the output of the laser from 3% to nearly 100%. Such a wide range of output is not possible from the laser alone. Figure 3 shows the detail of the attenuator. The attenuation is controlled by the angle of incidence. Normally the laser is 95%

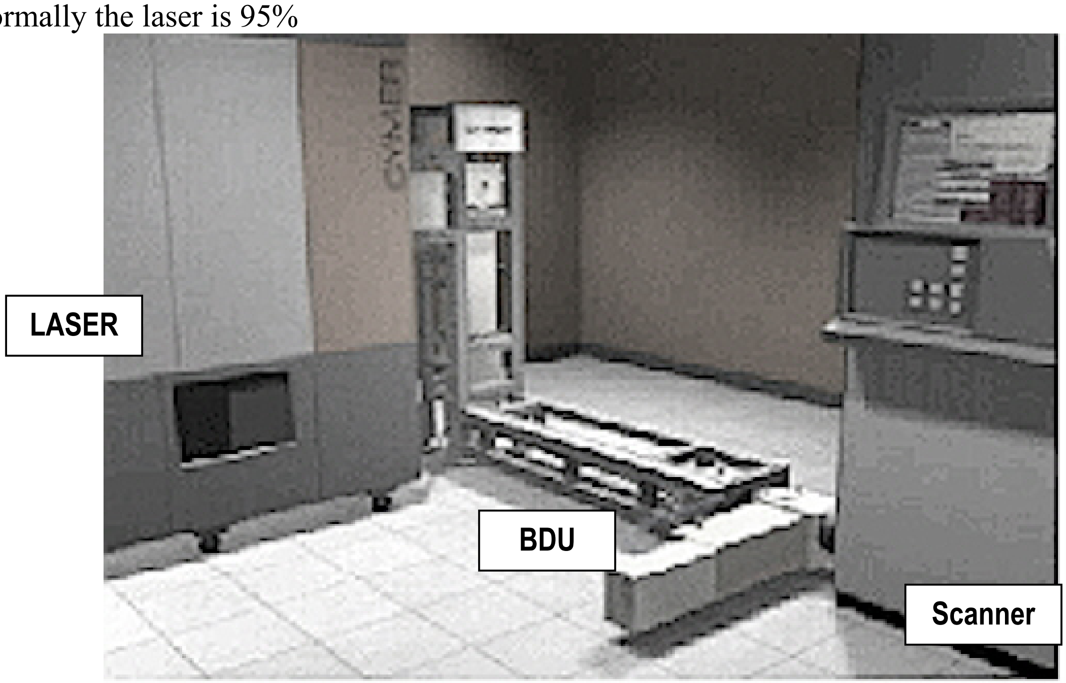

Figure 1: A BDU delivers light from the laser to a scanner.

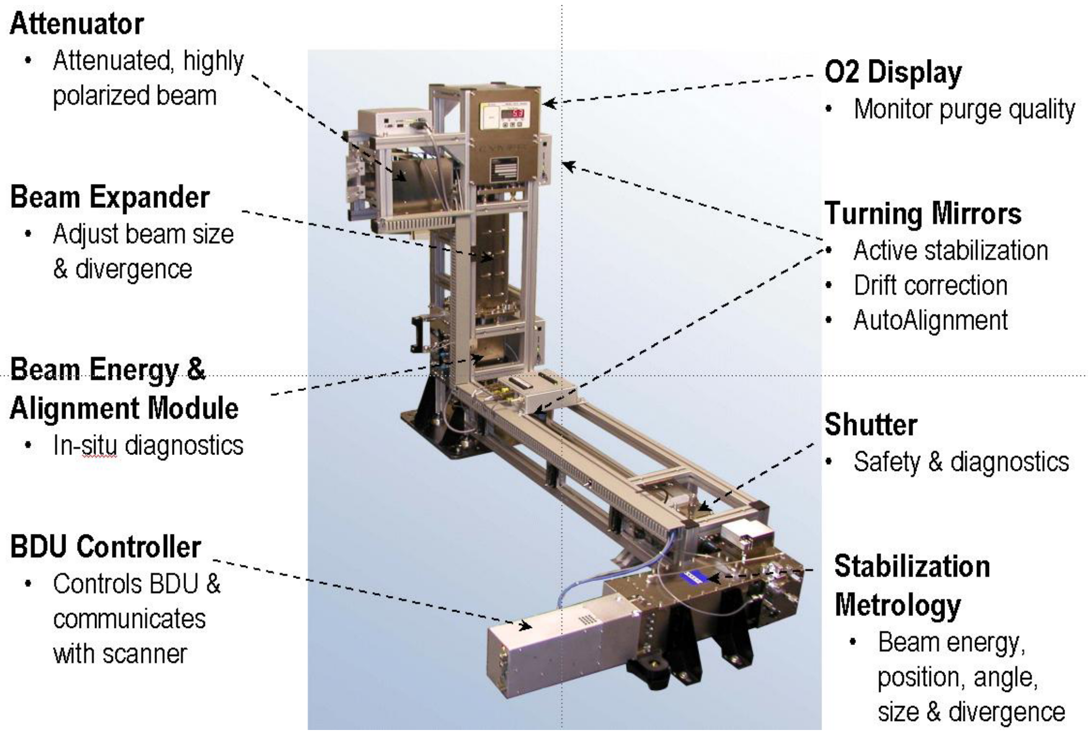

Figure 2: The details of BDU modules and their functions. The beam entry from the laser is at the attenuator and the beam exit from the BDU is at the stabilization module.

polarized in one direction (usually horizontal). The attenuator plates reject the remaining 5% and the output of the attenuator is a 100% polarized attenuated beam.

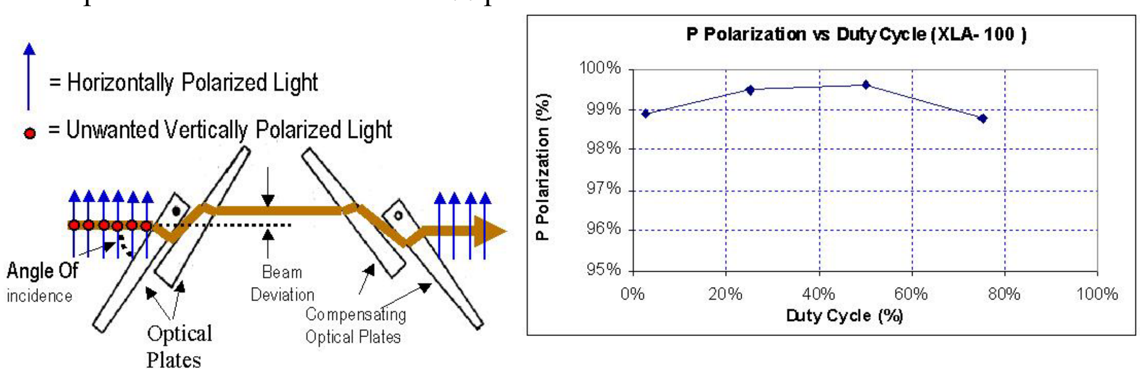

Figure 3: The attenuator rejects the unwanted polarization and presents to the scanner a ~100% linearly polarized light.

The beam is then turned 90 degrees with a turning mirror. The mirror is mounted on a fast steering motor and a slow adjustment motor, both of which are based on PZT technology. The laser's beam size and divergence usually do not match with the scanner requirements. The beam expander ensures the beam has the right size (typically 25 mm X 25 mm) and divergence (~1 mrad X 1 mrad). The second turning mirror is similar to the first. Just as the beam exits the BDU and enters the scanner, the stabilization metrology module measures the laser energy, beam size, beam divergence, beam position and beam pointing. The energy measurement supplements

energy measurements at the laser and in the scanner and helps isolate defective optics either in the scanner or in the BDU. The beam size and divergence measurements are used to monitor beam at scanner input and, as in the case of energy, can be used to isolate defective optics. The beam position and pointing are measured to ensure the beam is located and pointed correctly at the scanner input.

3.0 Performance

Stochastic processes can induce large beam pointing fluctuations from the laser. Thus a 100 µrad pointing fluctuation can cause a 2 mm beam position fluctuation at the exit of a 20 m long BDU. In addition floor vibrations due to scanner or other machinery could induce fluctuations in the beam angle. The BDU handles the pointing and position fluctuation using a closed-loop control involving the metrology module and the two turning mirrors. The technology and algorithm to maintain beam pointing and position is similar to laser's wavelength control. The metrology module generates signals proportional to the deviation of the beam position and angle, and the fast steering motors in the turning mirrors compensate for these deviations. The fast turning mirrors permit active single shot correction of beam position and angle – resulting in a well-aligned system during exposure. Figure 4 shows the beam position and pointing stability over 1.3 billion pulses. Figure 5 shows the impact of not having active stabilization – we show the performance of the BDU with control on and off. As one can see, without control, the beam pointing can deviate in excess of 200 µrad.

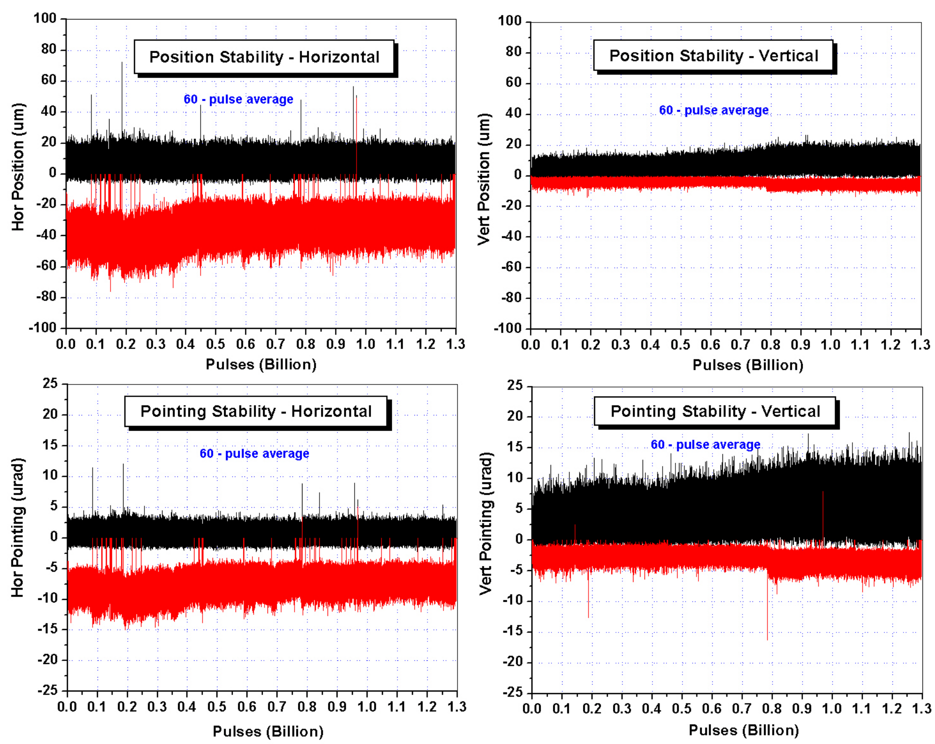

Figure 4: Beam position and pointing stability measured at the output of the BDU. The laser's energy is 10 mJ at 4000 Hz and was operated at duty cycles ranging from 6% to 75%.

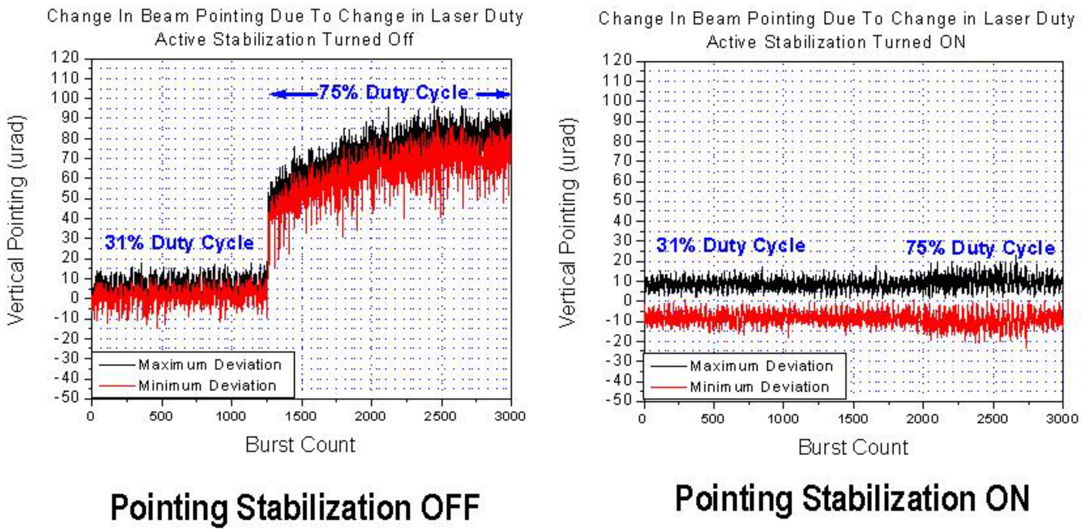

Figure 5: Beam angular drift (vertical) with and without active pointing stabilization.

What is the impact of beam pointing on the performance of the scanner? To understand this, we modeled a typical illuminator (Figure 6) used in a scanner. The illuminator is used to illuminate a reticle and we considered the change in uniformity on the reticle when beam angle is misaligned with respect to the axis (beam along axis is mot uniform). Figure 7 shows that the impact on the reticle uniformity as a function of beam angle misalignment. We see that a 100 µrad change can cause the reticle non-uniformity to exceed 0.2%.

This reticle non-uniformity increases CD error (Figure 8). A non-uniformity of 0.2% can cause a CD variation of 0.5nm. For advanced Microlithography, this is considered to be significant! On the other hand, with active beam stabilization, the beam angle can be maintained to within 25 µrad, leading to negligible CD variation.

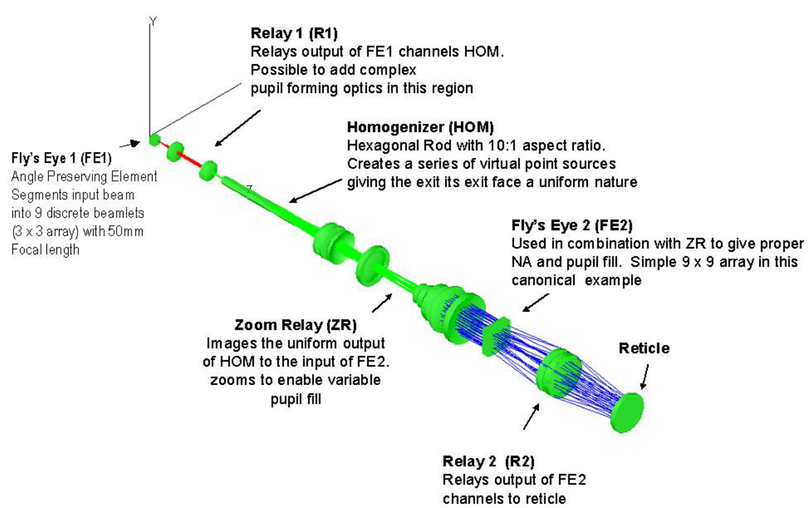

Figure 6. A typical illuminator, modeled by Dr. Russ Hudyma, Paragon Optics.

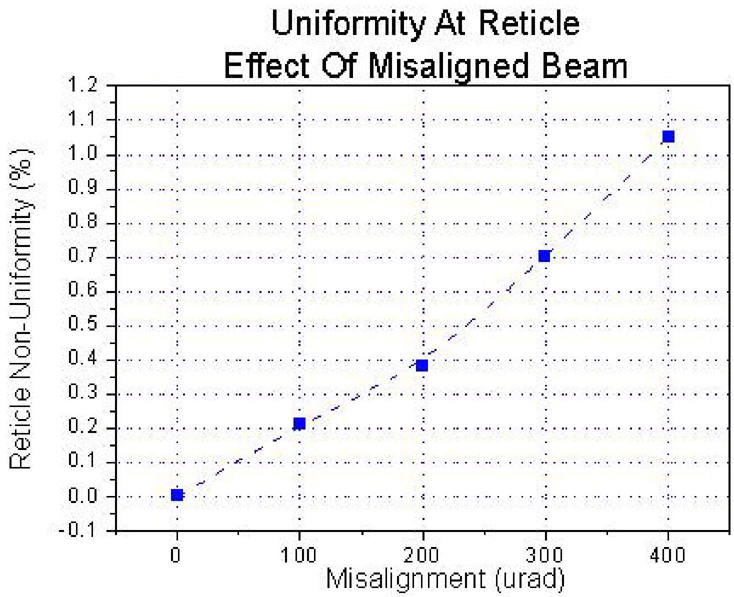

Figure 7. Beam angular misalignment in an illuminator causes reticle non-uniformity.

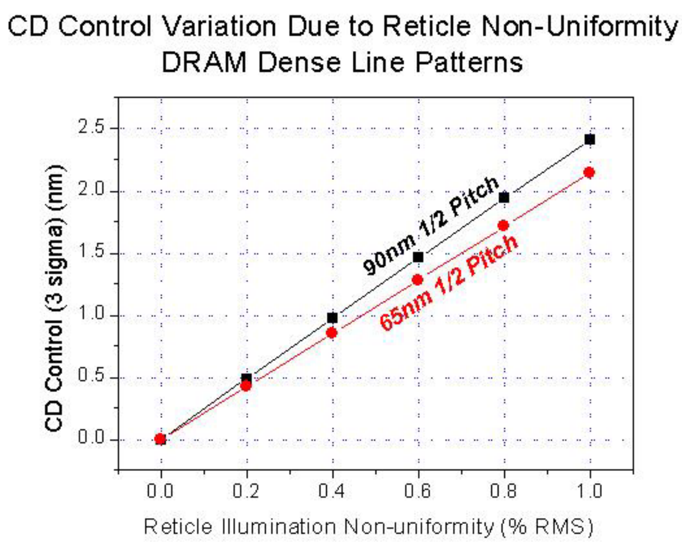

Figure 8. Reticle non-uniformity leads to loss of CD control. Dr. Alfred Wong, Fortis-Systems, modeled this effect.

4.0 Reliability

A problem that has been occasionally observed at 248 nm and now at 193 nm is a gradual degradation of BDU transmission despite the fact that the laser energy is maintained constant.

The degradation is usually significant, around 25 to 30% and occurs over 2 to 3 billion pulses. As a result, the intensity at the wafer decreases by the corresponding amount. Usually increasing the number of exposure pulses by 25 to 30% compensates this decrease in intensity. The degradation in transmission is normally due to contamination-induced damage of the BDU optics. The energy density in the BDU is much higher than in the scanner – typically 2 to 10 mJ/cm^2. Unless steps are taken to keep the contaminants low (hydrocarbons, oxygen etc.), the coated BDU optics can degrade rapidly. The technology of long life, contaminant-free opto-mechanical assemblies has already been developed in the laser. This explains why laser optical modules can last greater than 10 billion pulses without any degradation. By applying similar technologies, the lifetime of the BDU optics can be increased significantly. This is exactly what is shown in Figure 9. After 20 B pulses, the transmission of a BDU is unchanged. In other words, the intensity of light entering the scanner remained unchanged over 20 billion pulses. At 8 – 10 billion pulses per year scanner usage, this corresponds to over two years of operation.

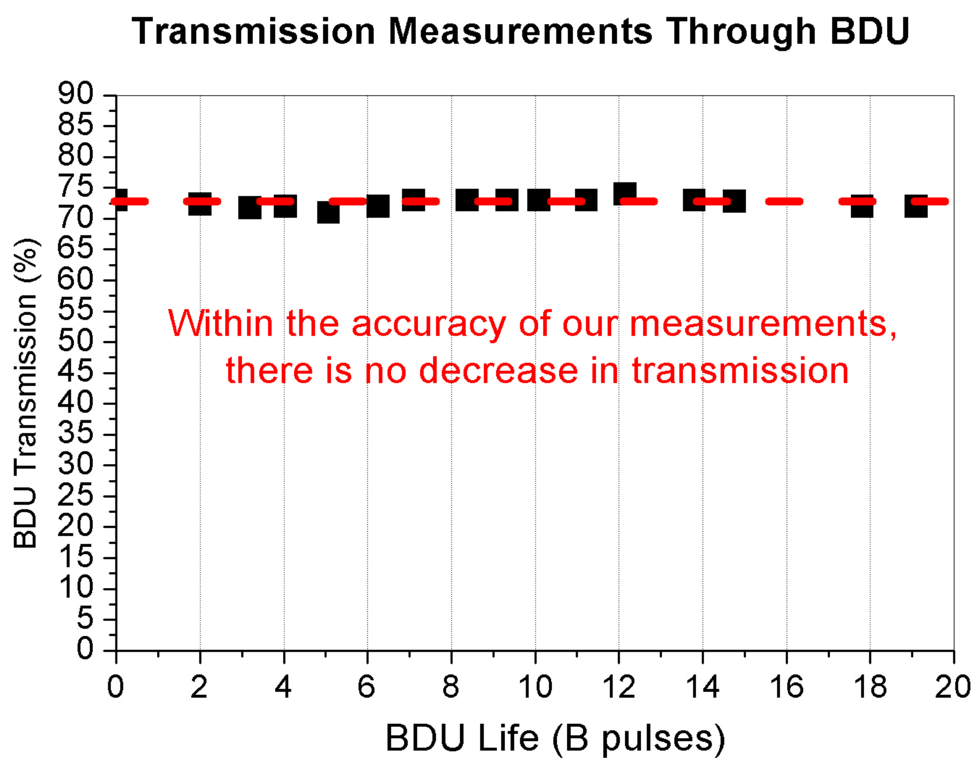

Figure 9. BDU transmission is unchanged in 20 billion pulses. This corresponds to more than 2 years of operation during which the input power to the scanner is unchanged.

5.0 Summary

In summary, we see that although laser performance has gone through rapid changes, there is a need to change how light is delivered to the scanner. Technology to do this effectively and efficiently already exists – in the laser. As a result, the scanner is assured laser beam with fixed, stable beam properties. And, the process engineer reaps the biggest benefits – CD control.